

TABLE OF CONTENTS

Chapter	Page
List of Tables	iii
List of Figures	v
1. INTRODUCTION	1
1.1 Study Objective	1
1.2 Methodology	1
1.3 Report Structure	2
2. THE FERTILISER INDUSTRY	3
2.1 Introduction	3
2.2 Types of Fertilisers and Classification	3
2.3 Industry Status	4
2.4 Overall Energy Consumption	11
3. NITROGENOUS FERTILISERS	16
3.1 Introduction	16
3.2 Ammonia	19
3.2.1 Synthesis Gas Production	19
3.2.1.1 Steam Reforming	21
3.2.1.2 Partial Oxidation	21
3.2.1.3 Coal Gasification	22
3.2.2 Shift Conversion	22
3.2.3 Purification of Synthesis Gas	22
3.2.4 Ammonia Synthesis	23
3.3 Urea	23
3.3.1 Industry Status	23
3.3.2 Technology Status	23
3.3.3 Production	25
3.3.4 Energy Use in Urea Production	29
3.3.5 Factors Affecting Energy Consumption	31
3.3.5.1 Feedstock	31
3.3.5.2 Technology	35
3.3.5.3 Capacity Utilisation	35
3.3.5.4 Age	36
3.3.5.5 Capacity	36
3.3.6 Regression Model - Specific Energy consumption	36

TABLE OF CONTENTS (Contd.)

Chapter	Page
3.4 Other Nitrogenous Fertilisers	42
3.4.1 Ammonium Sulphate	42
3.4.2 Calcium Ammonium Nitrate	45
3.4.3 Ammonium Chloride	45
4. PHOSPHATE FERTILISERS	48
4.1 Industry Status	48
4.2 Manufacturing Processes	48
4.2.1 Raw Material Requirements	53
4.3 Energy Use in Single Superphosphate	55
4.3.1 Energy Consumption	57
5. COMPLEX FERTILISERS	60
5.1 Introduction	60
5.2 Diammonium Phosphate	60
5.2.1 Manufacturing Process	60
5.2.2 Energy Use	63
5.3 Energy Use in N-P-K Fertiliser Mix	63
5.4 Ammonium Phosphate Sulphate	65
5.4.1 Manufacturing Process	65
5.4.2 Energy Use	65
ANNEXURE 1: THERMAL EQUIVALENT VALUES OF DIFFERENT FORMS OF ENERGY AND UTILITIES	70
NOTES	71
REFERENCES	72

LIST OF TABLES

Table No.	Page
2.1 Growth in Annual Installed Capacity of Fertilisers (Nutrients)	5
2.2 Production, Imports and Consumption of Fertilisers (Nutrients) 1984-85	7
2.3 Installed Capacity and Production of Different Fertilisers, 1984-85	8
2.4 Capacity Utilisation in the Fertiliser Industry	10
2.5 Overall Energy Consumption in the Fertiliser Industry	12
3.1 Growth in Production Capacity (Nutrient) of Straight Nitrogenous Fertilisers	17
3.2 Installed Capacity and Production of Nitrogenous Fertilisers, 1984-85	18
3.3 Zonal and National Characteristics of Urea Making Units, 1984-85	24
3.4 Urea Capacity according to Feedstock for Ammonia, 1984-85	26
3.5 Urea Capacity according to Processes for Ammonia, 1984-85	27
3.6 Growth of Stream Size in Ammonia and Urea Units in Indian Plants	28
3.7 Design Energy Consumption for Ammonia Plants with Natural Gas Feedstock	32
3.8 Design Energy Consumption for Urea Plants	33
3.9 Specific Energy Consumption for Urea Production from Different Feedstocks for Ammonia	34
3.10 Factorwise loss of Production in Nitrogenous Fertiliser Plants	37
3.11 Data for Urea Plants	39
3.12 Zonal and National Characteristics of Ammonium Sulphate Units, 1984-85	46
3.13 Ammonium Sulphate Capacity by Different Feedstocks, 1984-85..	47

Contd...

LIST OF TABLES (continued)

Table No.		Page
4.1	Growth in Annual Production Capacity of Straight Phosphatic Fertilisers	49
4.2	Production of Straight Phosphatic Fertilisers, 1984-85 ..	50
4.3	Zonal and National characteristics of Single Superphosphate Units, 1984-85	51
4.4	Installed Capacity of Sulphuric Acid, 1984-85	54
4.5	Production, Imports and Consumption of Phosphoric Acid for Fertiliser Industry, 1980-85	56
4.6	Specific Energy Consumption for Single Superphosphate ...	58
5.1	Growth in Annual Installed Capacity of Complex (N-P/N-P-K) Fertilisers (Materials)	61
5.2	Production of Complex Fertilisers, 1984-85	62
5.3	Specific Energy Consumption in the Manufacture of Diammonium Phosphate (DAP)	64
5.4	Specific Energy Consumption in the Manufacture of N-P-K Mix	66
5.5	Specific Energy Consumption in the Manufacture of Ammonium Phosphate Sulphate (APS)	68

LIST OF FIGURES

Fig. No.		Page
2.1	Growth in Annual Capacity of Fertilisers (Nutrients)	6
2.2	Fertiliser Industry; Breakup of Overall Consumption by Energy Form, 1982-83	14
3.1	Process Flow Diagram for Ammonia Production.....	20
3.2	Process Flow Diagram for Urea Making.....	30
3.3	Feedstock-Fuel Oil: Specific Energy Consumption for Urea Manufacture vs. Capacity Utilisation	43
3.4	Feedstock-Naphtha: Specific Energy Consumption for Urea Manufacture vs. Capacity Utilisation	44
4.1	Process Block Diagram for Single Superphosphate Manufacture	52
4.2	Breakup of Overall Energy Consumption in Single Superphosphate Manufacture.....	59
5.1	Process Flow Diagram for Ammonium Phosphate Sulphate Production.....	67
5.2	Breakup by Energy Forms in Ammonium Phosphate Sulphate Manufacture.....	69

1. INTRODUCTION

The fertiliser industry is one of the largest consumers of hydrocarbon energy. The major sources of energy utilised include naphtha, fuel oil, natural gas and coal. Other sources like high speed diesel, light diesel oil and electricity are also used. The fertiliser industry accounts for nearly 75 % of the naphtha and 38 % of the natural gas consumption in the country. Coal also contributes a large share in meeting the overall energy requirement of the industry.

The hydrocarbon sources of energy play a vital role in fertiliser production, especially in nitrogenous fertiliser production where they are used both as raw material and as fuel. Conservation of materials and energy would hence lead to substantial savings, reduced energy costs and also decrease in the import of petroleum products.

1.1 STUDY OBJECTIVES

The objectives of the study are:

- To determine current energy use pattern and consumption in the fertiliser industry.
- To understand energy usage in producing different types of fertilisers by different technologies, and to estimate the energy consumption for producing them.
- To identify the major factors affecting energy and materials consumption and to evaluate their relative effects on energy consumption.

1.2 METHODOLOGY

In keeping with the overall objective of the study, a questionnaire seeking specific energy-related information was developed and mailed to a sample of selected fertiliser manufacturing units throughout the country. The information asked for, included annual production, raw

materials consumption, forms of energy used and their quantities. In addition, operating characteristics of energy consuming devices like boilers, furnaces, reformers, stills etc.; electrical and mechanical drives; extent of instrumentation; and energy conservation measures adopted were also asked for.

Out of the 26 sample fertiliser units covered under the study, 14 units responded to the questionnaire. Data available from other sources was also used for the purpose of the analysis.

1.3 REPORT STRUCTURE

The report takes into account essentially the different types of fertilisers in use, viz. nitrogenous, phosphatic and complex.

Chapter 2 enunciates the status of the fertiliser industry. The evolution and growth of the industry, trends in consumption, production, imports and overall energy use have been presented.

Chapter 3 is on nitrogenous fertilisers and explains the production processes involved. Energy and material flows have been highlighted and factors affecting energy consumption identified. A mathematical model relating the different factors affecting energy consumption has also been developed.

In Chapter 4, the industry status of phosphatic fertilisers, the production steps involved and energy consumption for producing them have been given.

Chapter 5 gives the status of complex fertilisers. Production processes of two important complex fertilisers, diammonium phosphate and ammonium phosphate sulphate, have been explained and their energy use estimated.

2. THE FERTILISER INDUSTRY

2.1 INTRODUCTION

Fertilisers, in general, are substances which provide nitrogen, phosphorus and potassium in a form suitable for uptake by plants. All these substances are essential for the proper growth and development of plants at different stages. The fertiliser industry is thus closely linked with attempts to increase agricultural production and attain self-sufficiency. Each additional tonne of fertiliser in general is estimated to lead to eight additional tonnes of food grain.

2.2 TYPES OF FERTILISERS

Based on the presence of the three nutrients, nitrogen (N), phosphorus (P), and potassium (K), the composition of a fertiliser mixture in terms of the primary fertiliser elements is identified by an N-P-K code. N denotes elemental nitrogen; P denotes the anhydride of phosphoric acid, P_2O_5 ; and K denotes the oxide of potassium, K_2O : all are expressed numerically in percentage. A fertiliser represented by the code 18-46-0 would contain 18 % by weight of nutrient N and 46 % by weight of nutrient P. Depending on which of the above three nutrients are present, fertilisers are further classified into:

- Nitrogenous (N) ✓
- Phosphatic (P) ✓
- Potassic (K)
- Complex (N-P/N-P-K) ✓

Fertilisers in each category can thus be expressed in terms of material or quantity of the basic nutrient contents. A fertiliser containing a single nutrient only, e.g., urea (46 % N) is a straight nitrogenous fertiliser whereas single superphosphate (16 % P_2O_5) is a straight phosphatic fertiliser. A complex fertiliser contains two or more nutrients e.g., diammonium phosphate (18-46-0) etc.

2.3 INDUSTRY STATUS

At the beginning of 1986, there were 38 fertiliser units in the country, producing a wide range of nitrogenous and complex fertilisers. In addition, there were six units producing ammonium sulphate as a by-product in steel plants and around 60 units producing straight phosphatic fertilisers (Ministry of Chemicals and Fertilisers, Government of India, 1985).

The growth of the fertiliser industry has been significant, and today India ranks as the fourth largest producer of nitrogenous fertilisers in the world. The growth in installed capacity is shown in Table 2.1 and graphically in Figure 2.1. In spite of this rapid expansion in the fertiliser industry, fertilisers continue to be India's second largest import (after oil) year after year.

The country meets its entire potassic fertiliser requirement through imports and there are no facilities for the production of straight potassic fertilisers. Potassic fertilisers are imported in the form of muriate of potash (60 % K_2O) and sulphate of potash (50 % K_2O). Table 2.2 gives the country's production, import, and consumption of fertilisers for the year 1984-85.

The production capacities of different types of synthetic fertilisers -- straight nitrogenous, phosphatic and complex fertilisers are shown in Table 2.3. It is apparent from this table that capacity wise, nitrogenous fertilisers occupy the top position followed by complex and phosphatic fertilisers. Amongst nitrogenous fertilisers, urea has the largest installed capacity and contributes 82.8 % of the total nitrogen (N) capacity in the country. In phosphatic fertilisers, single superphosphate is the main fertiliser and constitutes 27.4 % of the total P_2O_5 nutrient capacity installed (Fertiliser Association of India, 1985). Table 2.4 gives overall capacity utilisation figures for the fertiliser industry for the period 1980-85.

Table 2.1

Growth in Annual Installed Capacity of Fertilisers (Nutrients)
(`000 tonnes)

Year	N	P ₂ O ₅
1951-52	88.7	31.7
1961-62	246.3	107.2
1971-72	471.2	502.6
1980-81	4735.8	1386.7
1981-82	5178.5	1511.7
1982-83	5201.3	1622.7
1983-84	5201.3	1631.6
1984-85	5923.6	1773.7

Source: Compiled from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

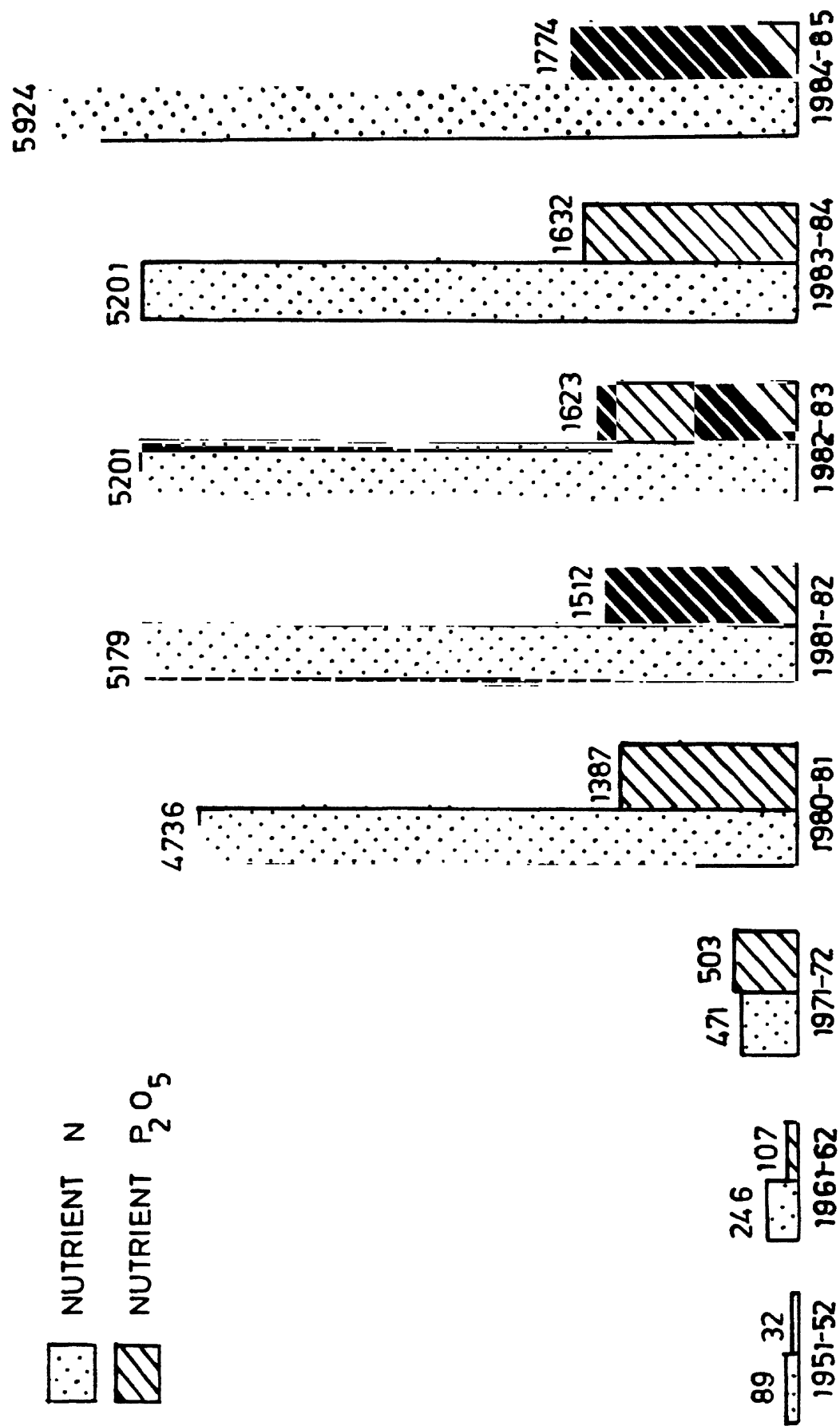


Figure 2.1 Growth in Annual Installed capacity of Fertilisers (Nutrients) - ('000 tonnes)

Note: Numbers rounded off to the nearest thousand tonnes

Table 2.2

Production, Imports and Consumption of Fertilisers (Nutrients), 1984-85
('000 tonnes)

	Production	Imports	Consumption
N	3917.3	2008.6	5486.0
P ₂ O ₅	1317.9	745.2	1886.4
K ₂ O	1/	871.0	838.5

1/ Not Produced

Source: Compiled from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

Table 2.3

Installed Capacity and Production of Different Fertilisers, 1984-85

Type	Fertiliser	Installed Capacity ('000 tonnes)	Production ('000 tonnes)	No of Plants in Operation
Nitrogenous	Urea (46 % N)	10657.0	6688.1	25
	Ammonium Sulphate (20.6 % N)	1073.2	454.0	13
	Calcium Ammonium Nitrate (25 % N)	800.0	409.2	2
	Ammonium Chloride (25% N)	217.8	77.9	5
Phosphatic	Single Super-phosphate (16 % P_2O_5)	3038.4	1697.5	58
	Triple Super-phosphate (40 % P_2O_5)	567.0	10.1	3
Complex	Diammonium Phosphate (18-46-0)	348.0	894.2 ^{2/}	5
	Ammonium Phosphate Sulphate (16-20-0)	51.5	57.4 ^{2/}	NA ^{1/}
	(20-20-0)	148.5	396.5	
	Nitrophosphate (15-15-15)	300.0	273.8	NA
	(20.7-20.7-0)	360.0	268.5	
	Other NP/NPKs (28-28-0)	2532.5	2299.6	NA
	(14-28-14)			
	(19-19-19)			
	(14-35-14)			
	(17-17-17)			
	(10-26-26)			
	(12-32-16)			

Contd

Table 2.3 (continued)

1/ Not available

2/ Production greater than capacity as also produced by units
licenced to manufacture other complex (N-P/N-P-K) fertilisers.

Source: Compiled from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

Table 2.4

Capacity Utilisation in Fertiliser Industry (%)

Year	Nitrogenous (N)	Phosphatic (P_2O_5)
80-81	45.6	60.6
81-82	60.6	62.8
82-83	65.9	60.6
83-84	67.1	65.2
84-85	67.0	74.3

Source: Estimated from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

In the course of its development and expansion, the fertiliser industry has successfully transferred and adopted several process technologies and developed its own facilities for preparing sophisticated designs, detailed engineering, fabrication, erection etc. Indigenous engineering and manufacturing capabilities so far contribute nearly 70 % of the equipment required for fertiliser plants (Ministry of Chemicals and Fertilisers, Government of India, 1985).

2.4 OVERALL ENERGY CONSUMPTION

It is a well-known fact that energy consumption in the fertiliser industry is considerable. The manufacture, packing, transport and application of 1 kg of nitrogenous fertiliser requires an estimated 2 kg of fossil fuels and those of 1 kg of phosphatic fertiliser 0.38 kg of fossil fuels. The nitrogenous fertiliser industry in particular is highly energy intensive and uses hydrocarbon energy forms as basic raw material and for providing process heat and motive power. The raw materials, referred to as feedstocks, include naphtha, fuel oil, gas, coal and even electricity. Fuels are used directly for process heating, in equipment like reformers etc., or for raising steam in boilers for process use and drives. Electricity is the source of motive power for driving equipment; alternatively, in some cases, steam turbine drives are used. In comparison with nitrogenous fertilisers, phosphatic fertilisers are less energy intensive and consume mainly electricity.

Table 2.5 gives the overall energy consumption in the fertiliser industry. The fact that the fertiliser industry, on an average, accounts for about 75 % of naphtha, 38 % of natural gas, 27 % of LSHS/HHS and 14 % of fuel oil consumption in the country for the years 1982-85, is an indication of the energy intensiveness of the industry. The percentage contribution of the different forms of energy for the year 1982-83, is shown in Figure 2.2. It is seen that naphtha with a share of 33 % is the largest contributor. This is due to the fact that a large proportion of the country's

Table 2.5

Overall Energy Consumption in the Fertiliser Industry

Energy form	Unit	82-83	83-84	84-85
Naphtha	(10 ³ tonnes)	2282 (77.1) ^{4/}	2134 (76.1)	2313 (74.4)
	Tcal ^{3/}	25102	23474	25443
Fuel Oil	(10 ³ tonnes)	670 (15.9)	574 (13.7)	390 (12.1)
	Tcal	6700	5740	3900
LSHS/HHS ^{1/}	(10 ³ tonnes)	883 (28.5)	913 (27.3)	687 (26.5)
	Tcal	8830	9130	6870
Natural Gas	(10 ⁶ cubic metres)	1155 (39.0)	1280 (37.6)	1603 ^{7/} (38.7)
	Tcal	10614	11763	14731
HSD/LDO ^{1/}	(10 ³ tonnes)	21 (0.2)	28 (0.2)	19 (0.2)
	Tcal	210	280	190
Coal	(10 ⁶ tonnes)	4.15 (3.2)	4.21 (3.1)	3.99 ^{7/} (2.7)
	Tcal	20750	21050	19950
Electricity ^{2/}	(10 ⁶ kWh)	4120 ^{5/} (4.3)	NA ^{6/}	NA
	Tcal	3543		
TOTAL	Tcal	75749		

Contd..

Table 2.5 (continued)

1/ LSHS - Low Sulphur Heavy Stock HSD - High Speed Diesel
HHS - Hot Heavy Stock LDO - Light Diesel Oil

2/ The total electrical energy consumed by the fertiliser industry consists of electrical energy purchased and generated internally. The consumption of coal, fuel oil etc., for internal generation of electricity is included in the consumption figures for the respective energy forms. Electricity consumption figures in the table are for purchased electrical energy only.

3/ Heating Values

Naphtha	: 11 Gcal/tonne	Electricity	: 860 kcal/kWh
Fuel Oil	: 10 Gcal/tonne	Coal	: 5 Gcal/tonne
LSHS/HHS	: 10 Gcal/tonne	Natural Gas	: 9.16 Gcal/1000m ³
HSD/LDO	: 10 Gcal/tonne		

1 Gcal = 10⁹ calories
1 Tcal = 10¹² calories
1 calorie = 4.18 Joules

4/ Figures in parentheses give consumption of the energy form in the fertiliser industry as a percentage of the total consumption in the country, e.g., out of the total quantity of naphtha consumed in the country, 77.1 % was consumed in the fertiliser industry.

5/ Data for 31 fertiliser plants only.

6/ Not Available

7/ Provisional figures for the year 1984-85.

Sources: Estimated from

1. Ministry of Petroleum, Government of India (1985), Indian Petroleum and Petro-chemicals Statistics, 1984-85, New Delhi.
2. Department of Coal, Ministry of Steel Mines and Coal, Government of India (1985), Annual Report. 984-85, New Delhi.
3. Central Electricity Authority, Government of India (1986), Public Electricity Supply - All India Statistics, General Review, 1982-83, New Delhi.

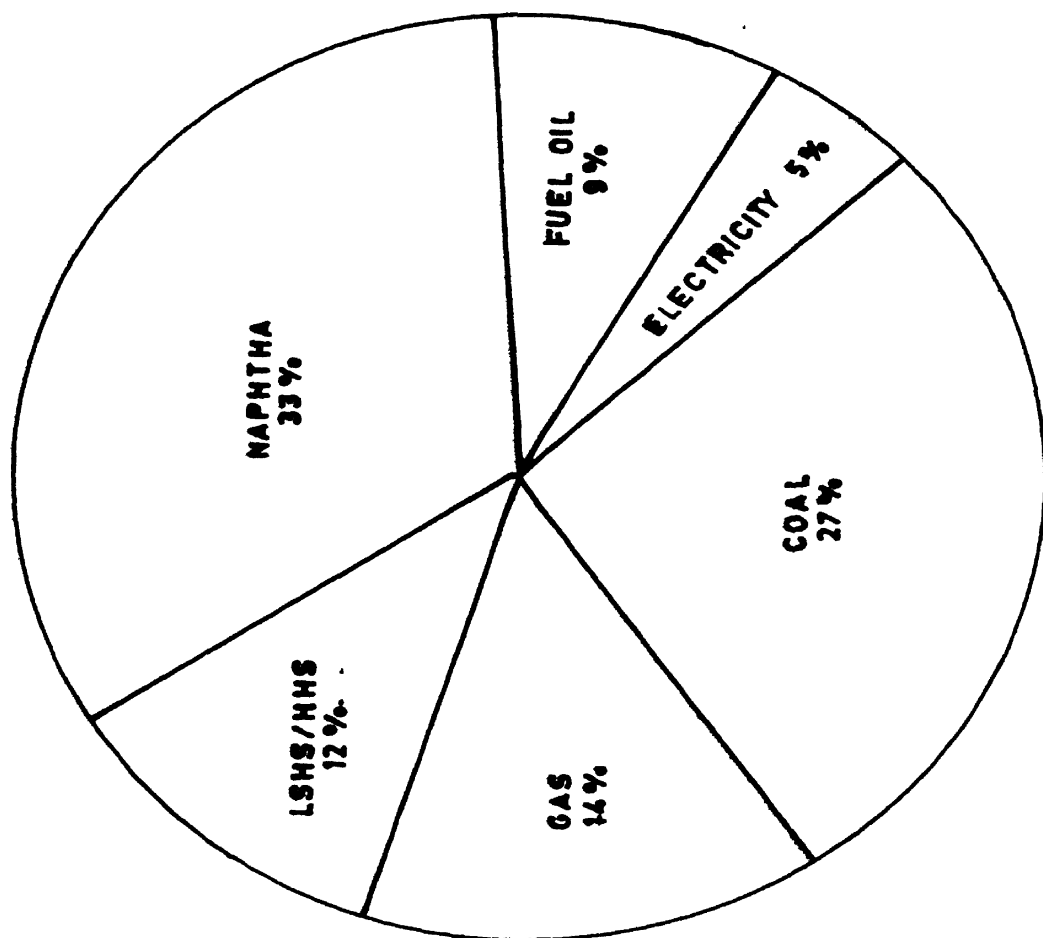


Fig. 2.2 Fertiliser Industry : Break up of Overall Energy Consumption by Energy Form, 1982-83

installed capacity of nitrogenous fertilisers is based on naphtha as feedstock. Coal, the next most intensively used source of energy, with a share of 27 %, is utilised mainly for generating steam and captive power.

3. NITROGENOUS FERTILISERS

3.1 INTRODUCTION

The nitrogenous fertiliser industry has undergone one of the largest expansion programmes experienced by any industry in the country. From a nominal capacity of 85,000 tonnes of nitrogen in 1951-52, production capacity of straight nitrogenous fertilisers has gone up to 5.4 million tonnes in 1984-85 (Ministry of Chemicals and Fertilisers, Government of India, 1985). Table 3.1 illustrates this rapid growth in production capacity.

This increase in production capacity has been brought about mainly to meet the greater demand generated for inorganic fertilisers by the country's Green Revolution programme and due to the thrust laid down by policy makers to increase yields of crops and attain self-sufficiency in food production.

Of the different types of nitrogenous fertilisers, urea (46 % N), ammonium chloride (25 % N), calcium ammonium nitrate (25 % N) and ammonium sulphate (20.6 % N) are the prominent few. Table 3.2 gives the individual installed capacity and production figures of these fertilisers for 1984-85.

In this section, the basic manufacturing processes for production of these fertilisers, the current status regarding capacity, technology etc., energy use, and factors affecting energy consumption have been presented. Ammonia production, the primary step in nitrogenous fertiliser manufacture, is discussed in Section 3.2. Urea, the most prominent amongst nitrogenous fertilisers, is dealt with in Section 3.3. A model relating specific energy consumption with the various factors affecting it has been developed and is also described in Section 3.3. Sections 3.4, 3.5 and 3.6 discuss the other straight nitrogenous fertilisers - ammonium sulphate, calcium ammonium nitrate and ammonium chloride.

Table 3.1

**Growth in Production Capacity (Nutrient) of
Straight Nitrogenous Fertilisers**

Year	Annual Capacity (`000 tonnes of N)
1951-52	85
1961-62	247
1971-72	1240
1980-81	4213
1981-82	4675
1982-83	4676
1983-84	4676
1984-85	5378

Source: Estimated from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

Table 3.2

Installed Capacity and Production of Nitrogenous Fertilisers, 1984-85

Fertiliser	Capacity ('000 tonnes)	Production ('000 tonnes)	Number of Units in Operation (as on 1-10-1985)
Urea	10657.0	6688.1	25
Ammonium Sulphate	1073.2	454.0	13
Calcium Ammonium Nitrate	800.0	409.2	2
Ammonium Chloride	217.8	77.9	5

Source: Estimated from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

3.2 AMMONIA:

Ammonia (NH_3), a compound consisting of nitrogen and hydrogen and containing 82 % nitrogen, is the basic building block of nitrogenous fertilisers. Production of ammonia can be broadly classified into, four major processes:

- Synthesis gas production
- Shift conversion
- Purification of synthesis gas
- Compression and ammonia synthesis

The first step in the manufacture of ammonia is the production of synthesis gas: a mixture of hydrogen and carbon monoxide, it can be obtained from several sources like naphtha, natural gas, coal etc. To produce more hydrogen and reduce the carbon monoxide content, the synthesis gas passes through a shift conversion reaction. It is further purified to obtain pure hydrogen by the removal of carbon dioxide and carbon monoxide. Nitrogen from air and purified hydrogen react at elevated pressures to produce ammonia.

Figure 3.1 gives the flow diagram for ammonia manufacture using gas/naphtha as feedstock.

3.2.1 Synthesis Gas Production

Ammonia is produced by reacting hydrogen with nitrogen. While nitrogen for the reaction is obtained from atmospheric air, hydrogen can be obtained from several sources, also referred to as feedstocks. Naphtha, fuel oil, natural gas, associated gas, coal and water are the sources from which hydrogen can be produced on a commercial scale. In India, fossil fuel sources like naphtha, fuel oil, coal and natural gas are the principal sources of hydrogen. Fertiliser plants located at integrated steel plants use raw coke oven gas as feedstock. A plant using electricity as feedstock wherein hydrogen is obtained by the electrolysis of water is also in operation.

FEEDSTOCK - NAPHTHA

DESULFURIZER

FUEL ———

**PRIMARY
REFORMER**

**COMPRESSED
AIR** ———

**SECONDARY
REFORMER**

**HIGH AND LOW
TEMPERATURE
SHIFT
CONVERSION**

**PURIFICATION
CO₂ REMOVAL**

METHANATION

**COMPRESSION
FOR AMMONIA
SYNTHESIS**

**AMMONIA
CONVERSION**

AMMONIA

Fig. 3.1 Process Flow Diagram for Ammonia Production

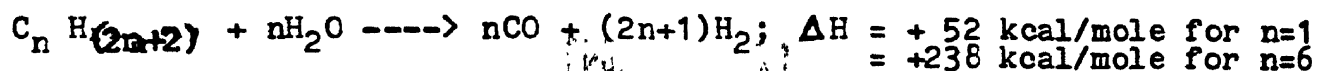
The major processes for manufacturing synthesis gas from different hydrocarbon feedstocks are:

- Steam reforming
- Partial combustion
- Coal gasification

3.2.1.1 Steam Reforming

The hydrocarbon feedstock (like naphtha) is mixed with steam and heated before being passed through a nickel catalyst bed in a fuel fired furnace called the primary reformer. The temperature in the primary reformer is around 790°C. The hydrocarbon feedstock gets converted to a mixture of hydrogen, carbon monoxide and carbon dioxide.

The reforming reaction is endothermic and can be represented as:



Heat contained in the reformer flue gases is recovered in a waste heat boiler by generating steam. The reaction continues in the secondary reformer where nitrogen in the form of compressed air is added so that eventually a nitrogen to hydrogen ratio of 1:3 on a volume basis is attained. The hot product gases from the secondary reformer (temperature around 930°C) are cooled by passing them through a waste heat boiler to generate steam or alternatively preheat the incoming air to the secondary reformer. The gases then enter the shift conversion system (Sittig, 1979).

3.2.1.2 Partial Combustion

This process has the advantage and capability of handling a variety of hydrocarbon feedstocks like gas, crude oil, fuel oil etc. The process can thus be used where light hydrocarbons are unavailable or expensive. It employs a noncatalytic partial combustion of the hydrocarbon feed with oxygen in the presence of steam in a combustion chamber at flame temperatures between 1300-1500°C to

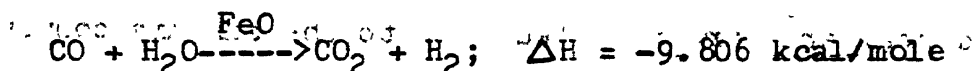
form carbon oxides and hydrogen. The reaction is exothermic, and for overall efficient operation, heat recovery from the product gas is important. The product gas has a composition that depends upon the carbon-hydrogen ratio of the feed and the amount of steam added. The three commercial versions of the process viz., Texaco, Shell and Montecatini differ primarily in the design and operation of the partial oxidation burner (Austin, 1985).

3.2.1.3 Coal Gasification

Gasification of coal is the first step whenever coal is to be used as a feedstock for production of synthesis gas. Synthesis gas is obtained by reacting coal with steam and oxygen in gasifiers which are of three types - fixed bed, entrained flow and fluidised bed.

3.2.2 Shift Conversion

The synthesis gas produced is introduced to a water gas shift reactor where carbon monoxide content is reduced and more hydrogen is produced. Shift conversion is represented by the following reaction:



The shift reaction is favoured by low temperature but is carried out in two steps - the high temperature shift conversion and the low temperature shift conversion. The heat released in the shift conversion reaction is recovered by generating steam.

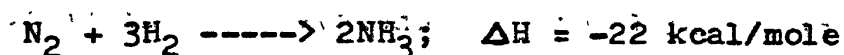
3.2.3 Purification of Synthesis Gas

Purification is aimed at removing carbon monoxide and carbon dioxide from the synthesis gas. Carbon dioxide is absorbed in a circulating chemical solution. The absorbed carbon dioxide gas is removed from the solution by means of a stripper. The final stage in synthesis gas preparation is to remove any traces of carbon monoxide and carbon dioxide. This is accomplished in a methanation unit in which residual carbon oxides are converted to methane in a nickel catalyst bed.

3.2.4 Ammonia Synthesis

The purified synthesis gas containing the right proportion of nitrogen and hydrogen is admitted to a special reaction vessel (converter) at elevated pressures in the presence of a metal oxide catalyst. Smaller plants operating at higher pressure use reciprocating compressors while new and larger plants operating at lower pressure use centrifugal compressors.

The ammonia synthesis reaction is:



To maintain the right reaction temperature (338-421°C), the heat released in the exothermic reaction is extracted by passing the product gas through a waste heat boiler for raising steam. The reaction being exothermic, care must be taken to obtain the optimum temperature which favours both the ammonia equilibrium and rate of reaction (Sittig, 1979). The product gases are then cooled to separate and condense ammonia. The ammonia is stored under pressure, at around 20 atmospheres. Conversion to ammonia being only partial, the unconverted reactants are recycled back to the ammonia converter.

3.3 UREA

3.3.1 Industry Status

As observed earlier, urea constitutes the largest proportion of fertiliser production in the country. The zonal and national characteristics of urea manufacturing units are shown in Table 3.3. Urea being a fertiliser of prime importance, production units are distributed more or less evenly throughout the country. This helps in forming a proper distribution network, ensures availability and eliminates bulk movement and transport.

3.3.2 Technology Status

Over the last thirty five years, technology of manufacturing

Table 3.3
Zonal and National Characteristics of Urea Making Units, 1984-85

Zonal and National Characteristics of Urea Making Units, 1984-85

	North Zone	South Zone	East Zone	West Zone	All India
Number of Units	6	6	5	8	25
Total annual capacity ('000 tonnes)	2806	2039	1870	3941	10657
Production ('000 tonnes)	2190.2	1488.7	1776.7	2230.5	6688.1
Mean age of Units (years)	9.2	11.2	9.0	9.6	9.8

1/ The country has been divided into four zones comprising the following states and union territories:

- NORTH** : Haryana, Himachal Pradesh, Jammu & Kashmir, Punjab, Uttar Pradesh, Chandigarh and Delhi.
- SOUTH** : Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Pondicherry and Lakshadweep Islands.
- EAST** : Assam, Bihar, Meghalaya, Mizoram, Nagaland, Orissa, West Bengal, Manipur, Sikkim, Tripura, Arunachal Pradesh and Andaman & Nicobar Islands.
- WEST** : Gujarat, Madhya Pradesh, Maharashtra, Rajasthan, Goa, Daman & Diu and Dadra & Nagar Haveli.

Source: Estimated from Fertiliser Association of India (1985), Fertiliser Statistics, 1984-85, New Delhi.

nitrogenous fertilisers, particularly synthesis gas manufacture from different feedstocks, has undergone much change. Table 3.4 shows that at present naphtha, natural gas and fuel oil are the three predominant feedstocks, accounting for more than 90 % of the ammonia required for urea production. Given the country's large coal reserves, coal was seen as an alternative feedstock following the oil crisis. Koppers - Totzek coal gasifiers have been installed in two coal-based fertiliser plants. These gasifiers operate at nearly atmospheric pressure and are capable of handling any quality of coal. The plants have faced initial teething problems but have successfully established the technological feasibility of direct gasification of coal. New finds leading to the availability of large quantities of natural gas have led to the implementation of large gas-based fertiliser projects. These projects will be carried out in phases, and are expected to be completed by 1988-89. The capacity of urea plants according to different manufacturing processes employed based on various feedstocks for ammonia production is shown in Table 3.5.

To gain advantage from the higher economies of scale in ammonia/urea manufacture, stream sizes of fertiliser plants in the country have shown a significant increase. Table 3.6 indicates how the sizes of plants have grown and evolved in the last few years. The world's largest single stream ammonia/urea plant, producing 1350 tonnes per day of ammonia and 1800 tonnes per day of urea was commissioned in 1982 by the Gujarat Narmada Valley Fertiliser Corporation at Bharuch in the State of Gujarat.


3.3.3 Production

Urea manufacture essentially consists of three steps:

- Ammonia and carbon dioxide are reacted at high pressure (137-341 atmospheres) and temperature (121-182°C) to form ammonium carbamate and urea solution

Table 3.4

Urea Capacity According to Feedstock for Ammonia, 1984-85

Ammonia Feedstock	Share of Capacity (%)
Naphtha	41
Petrogas ^{1/}	28
Fuel Oil	22
Coal	9 
TOTAL	100

1/ Includes Natural Gas, Associated Gas and Refinery Gas

Source: Estimated from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

Table 3.5

Urea Capacity According to Processes for Ammonia, 1984-85

Ammonia Process	Share of Capacity (%)
Naphtha reforming	39
Petrogas ^{1/} reforming	28
Fuel oil partial oxidation	22
Coal gasification	9
Naphtha partial oxidation	2
TOTAL	100

1/ Includes Natural Gas, Associated Gas and Refinery Gas

Source: Estimated from Fertiliser Association of India (1985), Fertiliser Statistics, 1984-85, New Delhi.

Table 3.6

Growth of Stream Size in Ammonia and Urea Units in Indian Plants

Year	Ammonia (tpd) ^{1/}	Urea (tpd)
1969	500	800
1974	900	1500
1982	1350	1800
1983	2 x 1350	3 x 1500

1/ tonnes per day

- Ammonium carbamate and urea are separated; ammonium carbamate is decomposed by steam to obtain ammonia and carbon dioxide which in turn are recycled.
- Urea solution is concentrated and pumped in to a prilling tower to obtain urea granules.

Urea production involves two chemical reactions. The first reaction is exothermic where ammonium carbamate is formed.



This is then followed by an endothermic decomposition of ammonium carbamate to form urea.

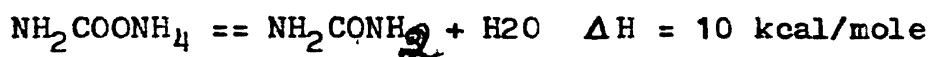


Figure 3.2 gives the flow diagram for urea manufacture.

3.3.4 Energy Use in Urea Production

The primary step in the manufacture of urea is ammonia production. Ammonia plants are extremely energy intensive and consume large amounts of energy both in the chemical process and in driving equipment. The cost of energy in ammonia production can represent as much as 80-90 % of the total cost in older plants and greater than 50 % for newer plants. Energy is consumed essentially in the form of feedstock, fuel and electric power. On a general scale it can be said that for ammonia produced from naphtha/gas-based plants, 55 % of energy is consumed in the form of feedstock, 44 % in the form of fuel and the rest in the form of electric power. For oil-based plants, 64 % of energy is consumed as feedstock, 33 % as fuel and the balance in the form of electric power (Bureau of Public Enterprises, Ministry of Finance, Government of India, 1985). Feedstock for coal based plants is around 80 % of the total energy consumed while fuel accounts for 15 %. The remaining 5 % energy is consumed in the form of electric power (Sittig, 1979).

Energy consumption in ammonia manufacture depends on the feedstock as well as the technology. Energy consumption is reduced when feedstock is changed from solids to liquids and from liquids to gas.

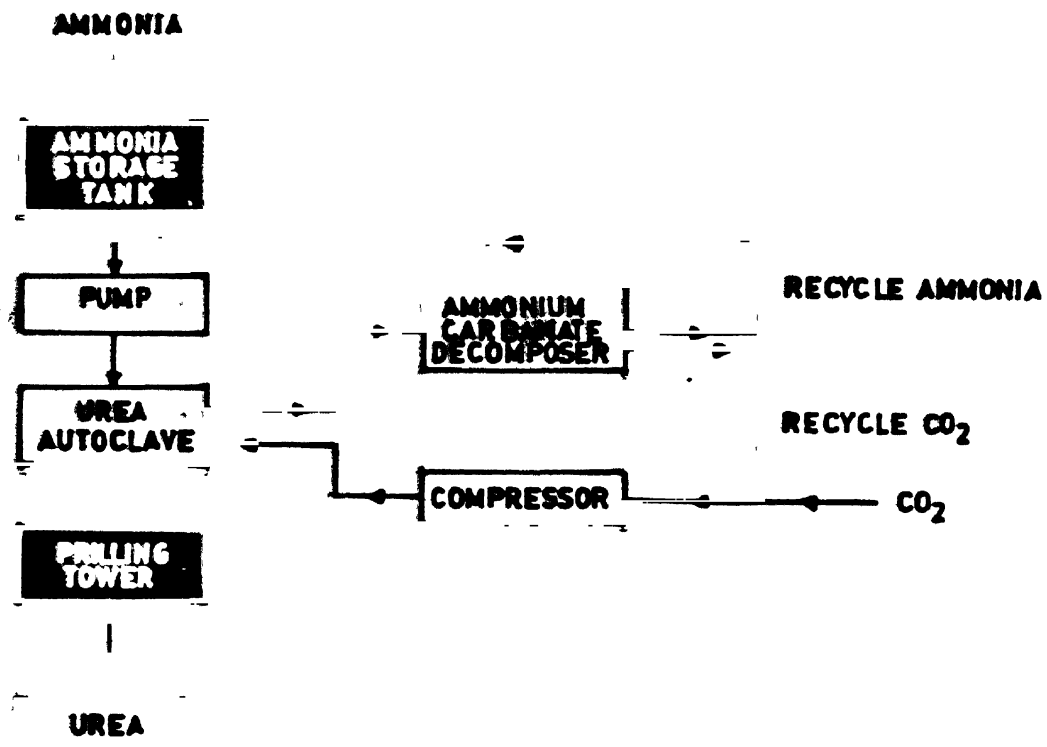


Fig. 3.2 Process Flow Diagram for Urea Making.

Modern ammonia plants based on improved process designs have reduced their energy consumption significantly. The energy consumption in ammonia production with natural gas as feedstock for different processes are shown in Table 3.7.

Urea production, which involves reacting ammonia and carbon dioxide, has evolved from the 'once-through' or no recycle process via partial recycle to total recycle. The recycling relates to that of ammonia, carbon dioxide and carbamate in solution. Table 3.8 indicates the process energy requirements per tonne of urea for different process technologies based on the total recycle process. The major process energy consumption is in the form of steam, followed by electricity.

Overall energy consumption figures for urea manufacturing units have been calculated from the responses to the study questionnaire mailed to selected sample units. Data presented in the report, Interfirm Comparison of Public Sector Fertiliser Plants, prepared by the Bureau of Public Enterprises, Ministry of Finance, Government of India, has been used to supplement the information gathered for the purpose of the analyses. Thermal conversion values for different energy forms are given in Annexure 1.

3.3.5 Factors Affecting Energy Consumption

It is observed that a variety of factors affect the energy consumption in ammonia and urea making like feedstock, technology, capacity, capacity utilisation factor etc. The effect of each factor on the overall energy requirements for urea production is discussed in the following sections.

3.3.5.1 Feedstock

Average specific energy consumption figures for urea production (including energy consumption in ammonia production) utilising different feedstocks for ammonia production are estimated and shown in Table 3.9. The results shown in Table 3.9 corroborate the

Table 3.7

Design Energy Consumption for Ammonia Plants with Natural Gas Feedstock

Process	Energy Consumption (Gcal/tonne NH ₃) ^{1/}
ICI AMV Process	7.56
C.F. Braun Process	7.80
Haldor Topsoe Low Energy Process	7.91
Snamprogetti Scheme	7.93
C.E. Lummus Process	8.03
Humphreys and Glasgow CEAD Process	8.06
Kellogg Process	8.34
KTI PARC Process	8.89

1/ 1 Gcal = 10⁹ calories
1 calorie = 4.18 Joules

Source: Krishnaswami, K.R. (1984), "Energy Conservation Efforts in MFL", Proceedings of Group Discussion on R&D in Energy Conservation in Fertiliser Industry/Research Centres - 1984, Feb 16-17, Fertiliser Association of India, New Delhi.

Table 3.8

Design Energy Consumption for Urea Plants

Process	Energy Consumption, (Gcal/tonne Urea) ^{1/}
Chemico	2.11
Stamicarbon	1.22
Snamprogetti	1.21
Mitsui Toatsu	1.16

1/ 1 Gcal = 10⁹ calories
 1 calorie = 4.18 Joules

Source: Estimated from Austin George, T. (1985),
Shreve's Chemical Process Industries,
 McGraw-Hill Book Company.

Table 3.9

Specific Energy Consumption for Urea production^{1/} from
different Feedstocks for Ammonia

Ammonia Feedstock	Energy Consumption ^{2/} (Gcal/tonne urea)	Average Capacity Utilisation (%)
Coal	29.01	26
Fuel Oil	12.70	73
Naphtha	13.30	65
Gas	8.95	90

1/ Includes energy consumption in ammonia production

2/ 1 Gcal = 10^9 calories
1 calorie = 4.18 Joules

Source: Estimated from study questionnaire responses.

observations that as one goes from heavier to lighter feedstock i.e., as feedstock is changed from fuel oil to naphtha or from naphtha to gas, specific energy consumption decreases (Chari, 1981). Energy consumption depends on the combined effect of several factors which include feedstock, capacity utilisation etc. One of the causes for the higher specific energy consumption of plants using naphtha as feedstock when compared with plants using fuel oil as feedstock could be the lower capacity utilisation of the naphtha-based plants surveyed.

3.3.5.2 Technology

Tables 3.7 and 3.8 have shown that energy consumption depends on the technology and process chosen. Recent advances in process technologies and catalysts have resulted in better consumption norms. For example, consumption of naphtha (feed and fuel) per tonne of ammonia guaranteed by various technology suppliers has come down during the '70s from 0.9-1.00 tonne to 0.8-0.85 tonne. Similarly, consumption of ammonia per tonne of urea has improved from 0.6 tonnes in the '70s to 0.58 tonnes in the '80s (Bureau of Public Enterprises, Ministry of Finance, Government of India, 1985).

3.3.5.3 Capacity Utilisation

From observations of plants' performance, it is generally seen that one of the major factors leading to improvement in energy consumption levels is continuous operation at high capacity. Plants operating at lower loads experience the same level of heat losses, purge losses and gas leaks as those functioning at rated or full load. With the increase in plant load, this constant loss has less impact on the overall energy consumption figures.

Given that the overall capacity utilisation for urea production is 63 % for the year 1984-85 (Fertiliser Association of India, 1985), there would appear to be substantial scope for improvement on energy consumption.

The major factors causing loss of production leading to lower capacity utilisation in nitrogenous fertiliser units are given in Table 3.10. The table indicates the need for greater emphasis on maintenance, especially when equipment breakdown is the major cause of suboptimal capacity utilisation. Power interruptions beyond half an hour also result in the intermediate products in the line having to be drained out so that pipelines and equipment in the urea plants do not get choked. Flaring of gas, steam venting etc., is done in the case of ammonia plants. These lead to higher consumption of raw materials and energy. To overcome loss of production due to power shortage, several units are installing captive generating plants.

3.3.5.4 Age

Energy consumption of all plants increases slightly with age due to wear and tear of equipment and loss in operational efficiencies. New plants usually encounter teething problems and suffer from frequent shutdowns and startups during the initial period before stabilisation. Hence their energy consumption is high during this period, though they are designed to be more energy efficient.

3.3.5.5 Capacity

To reap the benefits of economies of scale, stream sizes of urea making units has grown steadily (see Table 3.6) from 800 tonnes per day of urea in the '60s to 1500 tonnes per day urea in the '80s. The overall plant capacity, which is dependent upon the total number of streams in parallel has also increased.

3.3.6 Regression Model - Specific Energy Consumption

To quantify and assess the effects of different factors mentioned above, a multiple regression model was developed with energy intensity of urea (including energy for ammonia production) as an independent variable and other factors such as capacity, capacity utilisation factor, technology, and feedstock as dependent variables.

Table 3.10

**Factorwise Loss of Production in Nitrogenous Fertiliser Plants
(%)**

Factor	81-82	82-83	83-84
Equipment breakdown	48	58	49
Power problems	18	27	28
Shortage of raw materials	6	22	5
Labour problems	2	10	0.4
Others	26	3	18

Source: Vittal, N. (1985), "Fertiliser Units' Efforts to raise Productivity", Survey of Indian Industry, 1984, The Hindu, Madras.

The overall capacity of a plant, is the cumulative capacity of all streams operating in parallel. To assess the effect of capacity on the specific energy consumption, the average stream size of the urea plant in tonnes per day output was chosen as a dependent variable and is denoted by C. Capacity utilisation factor which is the ratio of actual production to that of installed capacity in percent, is indicated as CUF. To account for the wide variation in technologies of different urea plants and to compare plants operating on different technologies, the guarantee figure¹ for energy consumption in Gcal per tonne of urea as specified by the technology supplier was introduced as the third variable and represented as GRT. To assess the effect of feedstock, i.e., naphtha, fuel oil or gas, on the specific energy consumption of urea, two dummy variables were introduced. These variables assume the value of 1 or 0 depending on whether they are utilised as feedstock. The regression model has been derived from the data given in Table 3.11, excluding that given for coal.

It is seen that some plants achieve specific energy consumption figures lower than those of the guarantee figures. This is explained partly due to the margin provided by the technology suppliers to ensure that the plant operate at conditions guaranteed by the supplier.

The results obtained from the regression model are shown in Equations 1 and 2 which are two different ways of representing specific energy consumption of urea as a function of the set of independent variables. Equation 1 is in the log-log form while Equation 2 is in the semi-log form. Both Equations 1 and 2 indicate specific energy consumption with naphtha as feedstock with both the dummy variables D1 and D2 equal to zero.

knowing the stream size (C), capacity utilisation factor (CUF) and guaranteed energy consumption norms (GRT) for an urea plant, either of the two equations could be used to predict the specific energy consumption of urea. The coefficient of determination (R^2) for both the equations are comparable.

Table 3.11

DATA FOR UREA PLANTS

Capacity (tpd) ^{1/}	Guarantee (Gcal/tonne) ^{2/}	Capacity Utilisation (percent)	Specific Energy Consumption (Gcal/tonne) ^{3/}
Fuel oil			
1000	9.46	80.9	12.69
1000	9.46	78.7	11.56
1000	9.46	88.3	12.11
1000	10.26	77.0	13.59
1000	10.26	78.0	12.91
1550	9.49	77.5	11.01
1550	9.49	69.0	11.96
1550	9.49	67.0	12.15
Naphtha			
300	16.2	38.9	17.80
300	16.2	45.6	16.76
300	16.2	55.8	15.79
300	14.38	96.8	14.73
300	14.38	85.6	15.50
500	9.76	39.4	15.62
500	9.76	25.8	13.32
500	9.76	46.9	13.49
500	9.82	48.8	15.06
500	9.82	50.0	14.59
500	9.82	39.0	18.47
500	11.17	78.2	11.01
500	11.17	62.4	12.23
500	11.17	62.5	12.07
682	10.21	79.0	12.38
682	10.21	82.0	12.91
682	10.21	91.0	12.45
1550	9.33	79.0	10.37
1550	9.33	81.0	9.91
1550	9.33	65.2	10.97
Gas			
1000	7.556	98.6	7.26
1000	7.556	101.0	7.22
1000	7.556	96.6	7.19
Coal			
750	NA ^{4/}	20.8	32.47
750	-	25.8	28.48
750	-	32.8	26.08

Contd..

Table 3.11 (Contd.)

- 1/ tonnes per day
- 2/ 1 Gcal = 10^9 calories
1 calorie = 4.18 Joules
- 3/ Includes energy consumption in ammonia production
- 4/ Not Available

Source: Estimated from

1. Study Questionnaire Responses.
2. Bureau of Public Enterprises, Ministry of Finance,
Government of India (1985), Interfirm Comparison Study
of Public Sector Fertiliser Plants, New Delhi.

Regression - Model

Log-log model

$$\ln \text{ SEC} = 4.346 - \frac{0.1999}{(3.04)} \ln C - \frac{0.1801}{(3.04)} \ln \text{ CUF} \\ + \frac{0.1063}{(0.70)} \ln \text{ GRT} + \frac{0.1118}{(2.40)} \text{ D1} - \frac{0.3757}{(5.04)} \text{ D2} \quad \text{.. equation 1}$$

$$R^2 = 0.89$$

Semi-log model

$$\ln \text{ SEC} = 2.6989 - \frac{0.1935 \times 10^{-3}}{(3.50)} C - \frac{0.3406 \times 10^{-2}}{(3.40)} \text{ CUF} \\ + \frac{0.02146}{(2.20)} \text{ GRT} + \frac{0.0927}{(2.06)} \text{ D1} - \frac{0.3539}{(5.01)} \text{ D2} \quad \text{.. equation 2}$$

$$R^2 = 0.88$$

Note: Figures in parentheses below each regression coefficient indicate corresponding t-values.

SEC - Specific energy consumption of urea (includes energy for ammonia production), Gcal/tonne

C - Stream size of urea plant, tonnes per day

CUF - Capacity utilisation factor, percent

GRT - Guaranteed energy consumption of urea (includes energy for ammonia production), Gcal/tonne

D1 - Dummy variable; when fuel oil is feedstock D1 = 1 else D1 = 0

D2 - Dummy variable; when gas is feedstock D2 = 1 else D2 = 0

On examining the signs of the coefficients of different variables, it is seen that as the stream size and capacity utilisation factor increase, specific energy consumption decreases. Specific energy consumption has a direct relationship with the guarantee figures given by the technology supplier. An improved technology has a lower guaranteed energy consumption norm leading to lower specific energy consumption.

It is also seen from the model that specific energy consumption increases as the feedstock is changed from naphtha to fuel oil, whereas specific energy consumption decreases when gas is used as feedstock.

Figures 3.3 and 3.4 are scatter diagrams which illustrate the effect of the variation in specific energy consumption due to capacity utilisation, stream size and technology for the different feedstocks viz., fuel oil and naphtha.

Evaluation of elasticities² associated with each of the independent variables for a specific feedstock indicates that the most important variable affecting specific energy consumption is the stream size (C) of the urea plant.

3.4 OTHER NITROGENOUS FERTILISERS

Apart from urea, the other nitrogenous fertilisers produced are ammonium sulphate, calcium ammonium nitrate and ammonium chloride. A brief description of each one of them is given below. Specific energy consumption figures for these fertilisers could not be estimated since no data was available.

3.4.1 Ammonium Sulphate

Ammonium sulphate is manufactured by four different routes in the country. They are:

- Reacting ammonia with sulphuric acid.
- Reacting ammonia in solution with gypsum.
- Scrubbing ammonia dissolved in raw coke oven gas (produced in coke ovens in integrated steel plants) with sulphuric acid.

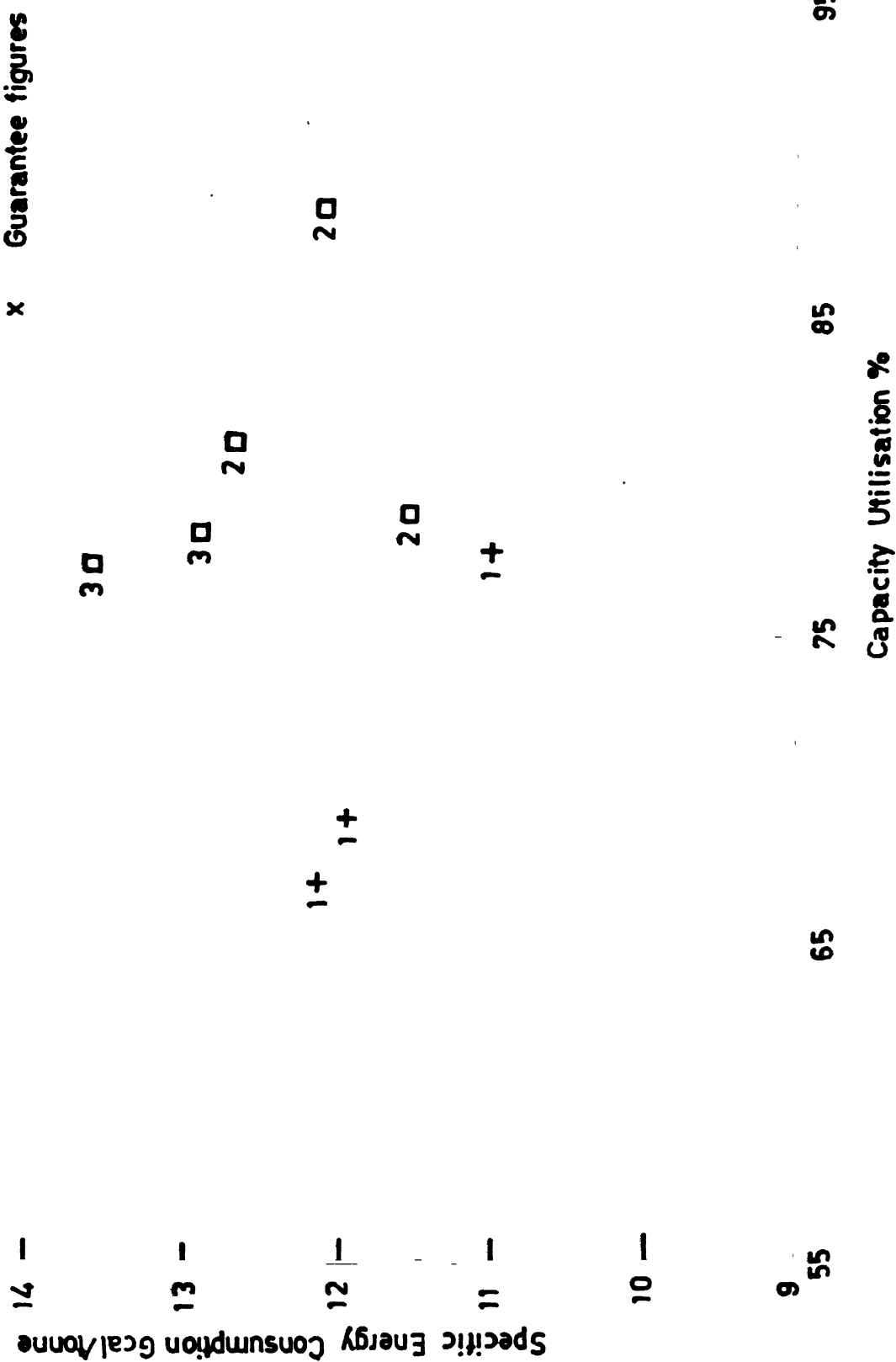


Fig. 3.3 Feedstock - Fuel Oil: Specific Energy Consumption for Urea Manufacture Vs Capacity Utilisation

Note: 1. Numbers indicate for different plants
2. Guarantee figures are at 100% capacity utilisation

Fig. 3.4 Feedstock - Naphtha: Specific Energy Consumption for Urea Manufacture Vs Capacity Utilisation

**Note: Numbers indicate for different plants
Guarantee figures are at 100% capacity utilisation**

- As a co-product of caprolactum production which is a raw material for nylon manufacture.

Ammonium sulphate produced by the "Inventa" process is obtained as a co-product in the manufacture of caprolactum, an intermediate for nylon production. Benzene is the principal raw material and typically 4 tonnes of ammonium sulphate are obtained per tonne of caprolactum produced (Kirk, 1972). The process is extremely attractive economically. One plant in the country uses the above process while another plant of similar capacity is under implementation and is to be completed by 1988.

In terms of capacity, amongst straight nitrogenous fertilisers, ammonium sulphate comes second only to urea. The zonal and national characteristics of operating ammonium sulphate units are shown in Table 3.12. It can be seen that the ammonium sulphate manufacturing units are clustered in the eastern zone. Some of the units situated in this region are part of integrated steel plants and use coke oven gas (COG) as feedstock. The total installed capacity as a share of the different feedstocks deployed is given in Table 3.13.

3.4.2 Calcium Ammonium Nitrate

Manufacture of calcium ammonium nitrate (nitrolime) consists of the following processes:

- Oxidation of ammonia to obtain aqueous nitric acid.
- Reaction between aqueous nitric acid and ammonia vapour to obtain ammonium nitrate.
- Reaction between ammonium nitrate and pulverised lime to obtain calcium ammonium nitrate.

3.4.3 Ammonium Chloride

Ammonium chloride is recovered as a co-product from modified Solvay process in the manufacture of soda ash. The ammonium chloride liquor obtained in the process is washed and allowed to crystallise. The resultant slurry is centrifuged and the crystals are dried in hot air rotary drums.

Table 3.12

Zonal^{1/} and National Characteristics of Ammonium Sulphate Units, 1984-85

	North Zone	South Zone	East Zone	West Zone	All India
Number of Units	Nil	2	7	3	12
Total annual capacity (`000 tonnes)	Nil	237	551	285	1073
Production (`000 tonnes)	Nil	111.6	85.7	256.7	454.0
Mean age of units (years)		28	23	7	19

1/ The country has been divided into four zones comprising the following States and Union Territories:

1. NORTH : Haryana, Himachal Pradesh, Jammu & Kashmir, Punjab, Uttar Pradesh, Chandigarh and Delhi.
2. SOUTH : Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Pondicherry and Lakshadweep Islands.
3. EAST : Assam, Bihar, Meghalaya, Mizoram, Nagaland, Orissa, West Bengal, Manipur, Sikkim, Tripura, Arunachal Pradesh and Andaman & Nicobar Islands.
4. WEST : Gujarat, Madhya Pradesh, Maharashtra, Rajasthan, Goa, Daman & Diu and Dadra & Nagar Haveli.

Source: Estimated from Fertiliser Association of India (1985), Fertiliser Statistics, 1984-85, New Delhi.

Table 3.13

Ammonium Sulphate Capacity by Different Feedstocks, 1984-85

	Percentage of total installed capacity	No. of Units
Synthetic ammonia	63	6
By product (COG ^{1/} as feedstock)	16	6
Caprolactum route	21	1

1/ Coke Oven Gas from integrated steel plants.

Source: Compiled from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

4. PHOSPHATIC FERTILISERS

4.1 INDUSTRY STATUS

Two straight phosphatic fertilisers, single superphosphate (16-20 % P_2O_5) and triple superphosphate (42-50 % P_2O_5) are manufactured in the country. P_2O_5 installed capacity in the country has increased from 63,000 tonnes in 1951-52 to 1.616 million tonnes at the end of 1984-85 (Ministry of Chemicals and Fertilisers, Government of India, 1985). The increase in production capacity of phosphatic fertilisers in the Five Year Plan, 1980-85, has been 31 %, as compared to a growth rate of nearly 43 % for nitrogenous fertilisers. Table 4.1 indicates growth in production capacity of the straight phosphatic fertiliser industry. All-India production figures of straight phosphatic fertilisers for the year 1984-85 are given in Table 4.2.

Installed production capacity of single superphosphate in the country is second only to that of urea. Table 4.3 gives the zonal and national distribution of these units. Of the 58 units producing single superphosphate, there are 17 units in the small scale industrial sector. These small units contribute nearly 10 % of the total installed capacity of single superphosphate in the country and are predominantly situated in the western zone.

4.2 MANUFACTURING PROCESSES

Production processes of the two types of superphosphates are mostly similar. Lumps of rockphosphate ore are mined, crushed and beneficiated. The beneficiated rockphosphate is mechanically ground to a particle size suitable for optimum process efficiency.

Figure 4.1 gives the flow diagram for single superphosphate manufacture. Single superphosphate is obtained by mixing ground rockphosphate with sulphuric acid to form a slurry. The reaction between the two is exothermic and occurs on a slow moving conveyor where the material becomes progressively plastic. Reaction time can vary between 1-4 hours depending on overall process conditions.

Table 4.1

Growth in Annual Production Capacity of
Straight Phosphatic Fertilisers
('000 tonnes)

Year	Installed capacity	
	SSP ^{1/}	TSP ^{2/}
1980	1634.4	567.0
1981	1836.9	567.0
1982	1869.9	567.0
1983	2074.5	567.0
1984	2416.6	567.0
1985	3038.4	567.0

1/ Single superphosphate

2/ Triple superphosphate

Source: Compiled from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

Table 4.2

Production of Straight Phosphatic Fertilisers, 1984-85

Fertiliser	Capacity ('000 tonnes)	Production ('000 tonnes)	No. of Units as on 1-10-85
Single superphosphate	3038.4	1897.0	58
Triple superphosphate	567.0	10.1	3

Source: Compiled from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

Table 4.3

Zonal^{1/} and National Characteristics of Single Superphosphate Units, 1984-85

	North Zone	South Zone	East Zone	West Zone	All India
No. of units	14	13	4	27	58
Capacity (`000 tonnes)	896.3	601.0	277.7	1263.4	3038.4
Production (`000 tonnes)	461.1	393.8	160.9	881.6	1897.0
Mean Age of Units (Years)	7	20	22	19	16

1/ The country has been divided into four zones comprising the following states and union territories:

1. NORTH : Haryana, Himachal Pradesh, Jammu & Kashmir, Punjab, Uttar Pradesh, Chandigarh and Delhi.
2. SOUTH : Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Pondicherry and Lakshadweep Islands.
3. EAST : Assam, Bihar, Meghalaya, Mizoram, Nagaland, Orissa, West Bengal, Manipur, Sikkim, Tripura, Arunachal Pradesh and Andaman & Nicobar Islands.
4. WEST : Gujarat, Madhya Pradesh, Maharashtra, Rajasthan, Goa, Daman & Diu and Dadra & Nagar Haveli.

Source: Estimated from Fertiliser Association of India (1985), Fertiliser Statistics, 1984-85, New Delhi.

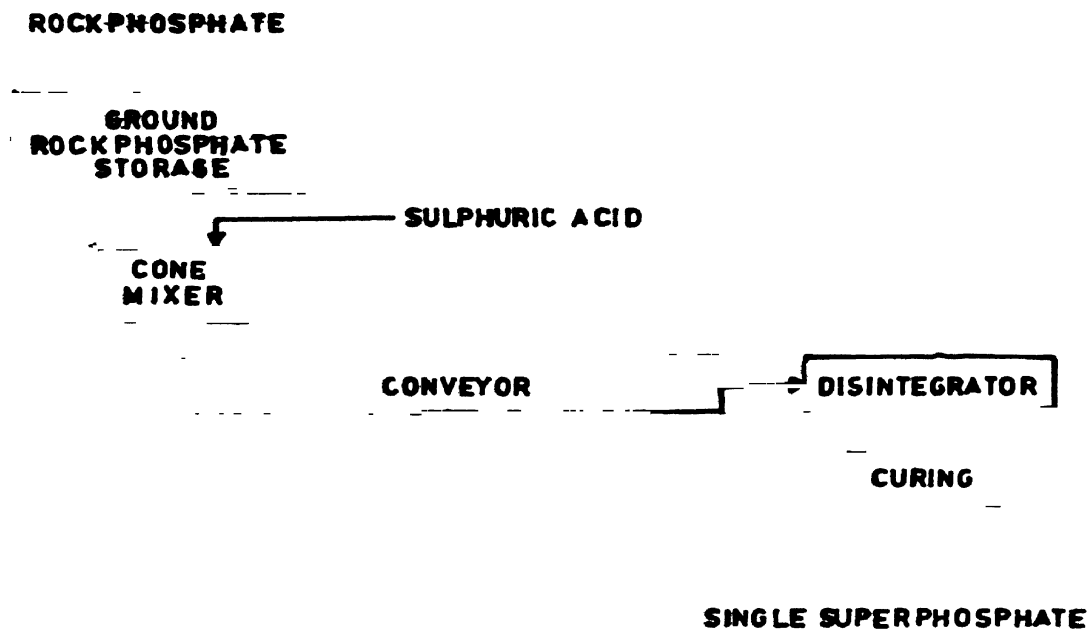


Fig. 4.1 Process Block Diagram for Single Super phosphate Manufacture

The product is then stored for 3-8 weeks for curing which enables completion of the reaction. The product is finally bagged before shipment. The process of manufacture is simple and easy to operate and can be adopted in small inexpensive plants.

Triple superphosphate is obtained by reacting ground rockphosphate with phosphoric acid. Triple superphosphate is much more concentrated in its P_2O_5 content, containing nearly three times the amount in single superphosphate.

4.2.1 Raw Material Requirements

The basic raw material requirements for straight phosphatic fertilisers are:

- Rock phosphate
- Sulphuric acid
- Phosphoric acid

Around 30 % of the country's rock phosphate needs for phosphatic fertiliser manufacture are met indigenously and the rest by imports.

Sulphuric acid is obtained from processes based on

- Elemental sulphur
- By-product from copper smelters
- By-product from zinc smelters
- Iron pyrites

The number of units and the percentage break up of installed capacity of sulphuric acid plants in each of these categories is given in Table 4.4. It may be observed that a large percentage of sulphuric acid manufacturing capacity is based on elemental sulphur. The country imports sulphur to augment its local supply to meet sulphuric acid demand.

Phosphoric acid is one of the principal ingredients for triple superphosphate. Phosphoric acid is obtained by reacting finely ground rockphosphate with strong sulphuric acid. The resultant acid slurry

Table 4.4

Installed Capacity of Sulphuric Acid, 1984-85

Sulphuric acid production based on	Capacity ('000 tonnes)	No. of Units
<hr/>		
Elemental Sulphur	3860	90
By-product from copper smelters	236	2
By-product from zinc smelters	189	3
Iron pyrites	264	1
TOTAL	4549	96

Source: Compiled from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

is separated into gypsum cake and phosphoric acid on a travelling pan filter.

The nation's deficit in phosphoric acid requirements is met by imports. Table 4.5 gives production, imports and consumption of phosphoric acid for the years 1980-85.

4.3 ENERGY USE IN SINGLE SUPERPHOSPHATE

Since the major ingredients of single superphosphate are sulphuric acid and rockphosphate, the energy intensity of a product like single superphosphate is almost entirely composed of indirect energy supplied by its constituent raw materials i.e., sulphuric acid and beneficiated rock phosphate. The energy analysis of sulphuric acid production and mining and beneficiation of rock phosphate is thus a prerequisite for energy analysis of single superphosphate.

Sulphuric acid is produced in India by two processes:

- Contact Process
- Double Contact Double Absorption Process (DCDA)

The DCDA process is a later development and is more energy efficient than the conventional Contact process which is widely practiced in India. In 1985 there were 96 units manufacturing sulphuric acid in the country with a total annual capacity of 4.55 million tonnes, 40 % of which is based on the DCDA process (Fertiliser Association of India, 1985; Ashar, 1984). The exothermic reaction involved in sulphuric acid production generates by-product steam. The large scale utilisation and adoption of steam-driven drives or power generation from steam is yet to be realised in sulphuric acid plants in the country. This is largely due to the uneconomical sizes of plants for generation of steam at higher quantities and pressures.

Rockphosphate requires energy for mining, grinding, and beneficiation. The energy requirement for these operations depends on the extent of overburden, structure of the raw rock and the quantity of foreign materials present.

Table 4.5

Production, Imports and Consumption of Phosphoric Acid^{1/}
for Fertiliser Industry, 1980-85

(tonnes of P_2O_5 ^{2/})

Year	Production	Imports	Consumption
80-81	275,226	365,320	586,137
81-82	270,973	441,126	710,010
82-83	256,683	393,136	657,389
83-84	246,422	516,405	765,043
84-85	266,453	616,633	927,434

1/ Expressed as 100 % P_2O_5

2/ Data in respect of one factory not available

Source: Compiled from Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

4.3.1 Energy consumption

Based on responses to the study questionnaire, the specific energy consumption for single superphosphate manufacture was calculated for different years and the results are shown in Table 4.6. For arriving at the specific energy consumption figures, process energy consumption attributable to sulphuric acid manufacture have been considered but energy required for rockphosphate preparation like mining etc., have not been accounted for. The breakup of energy consumption by different forms for Plant 1 has been shown in Figure 4.2. Energy requirement of triple superphosphate can likewise be estimated by analysing energy requirement of phosphoric acid.

Table 4.6

Specific Energy Consumption for Single Superphosphate^{1/}

Year		1	2	3	4	5
Plant 1	Energy Consumption ^{2/} (Gcal/tonne)	0.094	0.095	0.103	0.107	0.089
	Sulphuric acid Capacity Utilisation (%)	73	62	55	59	86
	Single Superphosphate Capacity Utilisation (%)	72	65	57	56	82
Plant 2 ^{3/}	Energy Consumption (Gcal/tonne)	0.096	0.098	0.100	0.131	0.156
	Sulphuric Acid Capacity Utilisation (%)	64	50	42	35	63
	Single Superphosphate Capacity Utilisation (%)	23	34	34	32	33

1/ Includes energy consumption for sulphuric acid manufacture; energy requirements for preparation of rockphosphate not accounted for.

2/ 1 Gcal = 10⁹ calories
1 calorie = 4.18 joules

3/ Obtains sulphuric acid from byproduct gas from smelter

Source: Computed from study questionnaire responses.

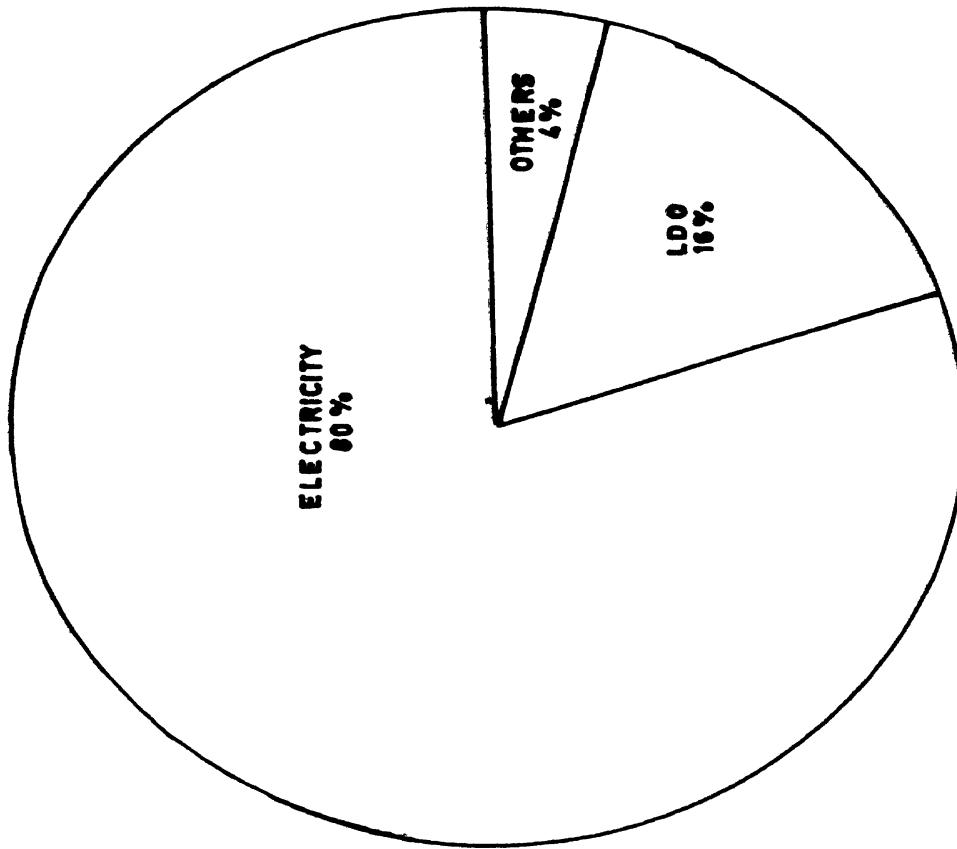


Fig. 4.2 Break up of Overall Energy Consumption in Single Superphosphate Manufacture

Note: Numbers are for a single plant.

5. COMPLEX FERTILISERS

5.1 INTRODUCTION

Production of compounds of primary fertiliser elements has always been of interest to the fertiliser industry. Economy favours the single application of a balanced mixture that satisfies all nutritional needs of a crop. Since each primary element can be supplied in any number of different chemical compounds, or basic fertiliser substances, the practice has given rise to great diversity of formulations. Complex fertilisers are essentially a mix of nitrogenous and phosphatic (N-P) or a mix of nitrogenous, phosphatic and potassic (N-P-K) fertilisers. A wide array of compositions are marketed to suit the need of specific crops and the specific soils on which they are grown. Table 5.1 indicates the overall growth in installed capacity of complex fertilisers in the country.

Prominent amongst the complex fertilisers are diammonium phosphate (DAP, 18-46-0), ammonium phosphate sulphate (APS, 16-20-0, 20-20-0), and urea ammonium phosphate (UAP, 28-28-0). In addition, there are a series of N-P/N-P-K fertiliser mix of different compositions such as (24-24-0), (19-19-19), (15-15-15), (14-35-14) etc. Table 5.2 gives production levels of these fertilisers in the country for the year 1984-85. Since mixed fertiliser plants have capabilities of producing a wide range of N-P-K fertilisers of different proportions, the units are generally equipped with facilities for producing ammonia, sulphuric acid and phosphoric acid.

5.2 DIAMMONIUM PHOSPHATE

5.2.1 Manufacturing Process

Vapour or liquid anhydrous ammonia is reacted with phosphoric acid (30-40 % P_2O_5) in a vertical cylindrical vessel which may or may not have mechanical agitation. The resultant slurry formed is pumped into a mixer from where it is distributed on to the surface of dry

Table 5.1

Growth in Annual Installed Capacity of
Complex (N-P/N-P-K) Fertilisers (Materials)

Year	Installed Capacity (`000 tonnes)
1970	7 80.5
1975	1 131.0
19 80	2 849.4
19 81	3 235.5
19 82	3 235.5
19 83	3 385.5
19 84	3 385.5
19 85	3 740.5

Source: Fertiliser Association of India (1985),
Fertiliser Statistics, 1984-85, New Delhi.

Table 5.2

Production of Complex Fertilisers, 1984-85

Fertiliser	Production (`000 tonnes)	Capacity (`000 tonnes)	No. of units as on 1-10-85
Diammonium Phosphate (DAP)	894.2 ^{1/}	346.0	5
Ammonium Phosphate Sulphate (APS)	454.0 ^{1/}	200.0	3
Urea Ammonium Phosphate (UAP)	267.6	NA ^{2/}	4

1/ Production greater than capacity, as also produced by units licensed to manufacture other complex (N-P/N-P-K) fertilisers.

2/ Not Available

Source: Estimated from Fertiliser Association of India (1985), Fertiliser Statistics, 1984-85, New Delhi.

recycled finished material. A ratio of 1.3-1.5 moles of ammonia per mole of phosphoric acid is maintained to obtain optimum fluidity of the slurry. Distribution and mixing takes place in either a pug mill, which is a longitudinal trough containing two parallel shafts with short heavy-duty paddles, or a rotating drum. Wetted granules then discharge into a rotary dryer and excess water is evaporated. Part of the dried granules are separated for use as recycle material. Product sized granules are cooled and conveyed to storage or shipped directly.

5.2.2 Energy Use

Diammonium phosphate manufacture is generally a part of a complex unit manufacturing several other fertilisers. It is difficult to identify and apportion energy requirements for a particular type of fertiliser in such a mix.

To overcome this problem of apportioning energy for DAP manufacture in a plant producing both urea and DAP, energy requirement for urea manufacture was predicted using Equation 2, generated by regression runs. Knowing the overall energy consumption of the fertiliser unit, the energy intensity of DAP can be estimated as the difference between the total and that predicted for urea. These calculations are shown in Table 5.3 and it can be seen that energy intensity of DAP manufacture depends on its capacity utilisation factor.

5.3 ENERGY USE IN N-P-K FERTILISER MIX

The methodology outlined above was used to find the energy intensity of a plant manufacturing urea and an N-P-K complex fertiliser mix, consisting of 17-17-17, 14-28-14, 24-24-0, 18-46-0. Using Equation 2 and knowing the plant's characteristics such as stream size, guarantee, and capacity utilisation factor, specific energy consumption of urea was calculated. Energy intensity of the N-P-K complex fertiliser mix was estimated as the difference between the total energy consumption in the plant and that predicted for urea.

Table 5.3

Specific Energy Consumption in the Manufacture of Diammonium Phosphate (DAP)^{1/}

Year	1	2	3	4	5 ^{2/}
Total Energy Consumption (Urea + DAP) (Gcal) ^{3/}	3999	3472	4161	4349	6837
Energy Intensity of Urea ^{4/} (Gcal/tonne)	9.78	10.12	9.52	9.35	9.13
Urea Energy Consumption (Gcal)	3631	3202	3931	4009	6440
DAP Production (`000 tonnes)	49.7	79.6	96.8	139.1	222.3
Energy Intensity of DAP (Gcal/tonne)	7.4	3.4	2.3	1.8	1.7
Capacity Utilisation Factor DAP (%)	31	50	60	87	93

1/ For one plant only

2/ Numbers given for 18 months

3/ 1 Gcal = 10^9 calories
1 calorie = 4.18 Joules

4/ Estimated from Equation 2

Source: Estimated from study questionnaire response.

This is shown in Table 5.4. The data given is for one plant only and allows us to estimate as a whole and not by type of N-P-K.

5.4 AMMONIUM PHOSPHATE SULPHATE

5.4.1 Manufacturing Process

Ammonium phosphate sulphate (APS) manufacture requires the presence of ammonia, sulphuric acid and phosphoric acid units to provide the basic raw material ingredients and intermediates. A plant manufacturing only APS would require all the three streams to be closely matched to achieve greater operational efficiency and better overall integration. For e.g., excess of steam generated in the sulphuric acid plant could be effectively utilised in the ammonia plant.

The basic process involved in APS production is shown in Figure 5.1. Reactors or saturators are charged with gaseous ammonia, strong sulphuric acid and weak phosphoric acid. Water is added at this stage via scrubbers to maintain control over the reaction which occurs with heat of neutralisation being released. The product is then dried downstream and pulverised before being packed for use.

5.4.2 Energy Use

The energy intensity of APS was calculated from the questionnaire response for a plant manufacturing APS only. The results are presented in Table 5.5. The energy required for producing the intermediate products ammonia, phosphoric acid and sulphuric acid has been included in the analysis. The break up of different forms of energy and their percentage contribution is shown in Figure 5.2.

Table 5.4

Specific Energy Consumption in the Manufacture of N-P-K Mix^{1,2/}

Year	1	2	3	4	5
Total Energy Consumption (Urea + N.P.K) (Gcal)	3262	2898	3479	3287	3107
Energy Intensity of Urea ^{3/} (Gcal/tonne) ^{4/}	12.10	12.47	12.01	12.70	13.32
Urea energy Consumption (Gcal)	1752	1569	1788	1459	1137
N-P-K Production ('000 tonnes)	556	485	557	581	603
Energy Intensity of N-P-K Complex mix (Gcal/tonne)	2.71	2.74	3.03	3.14	3.76

1/ 17-17-17
 14-28-14
 24-24-0
 18-46-0

2/ For one plant only

3/ Computed from Equation 2

4/ Gcal = 10^9 calories.
 1 calorie = 4.18 Joules

Source: Estimated from study questionnaire response.

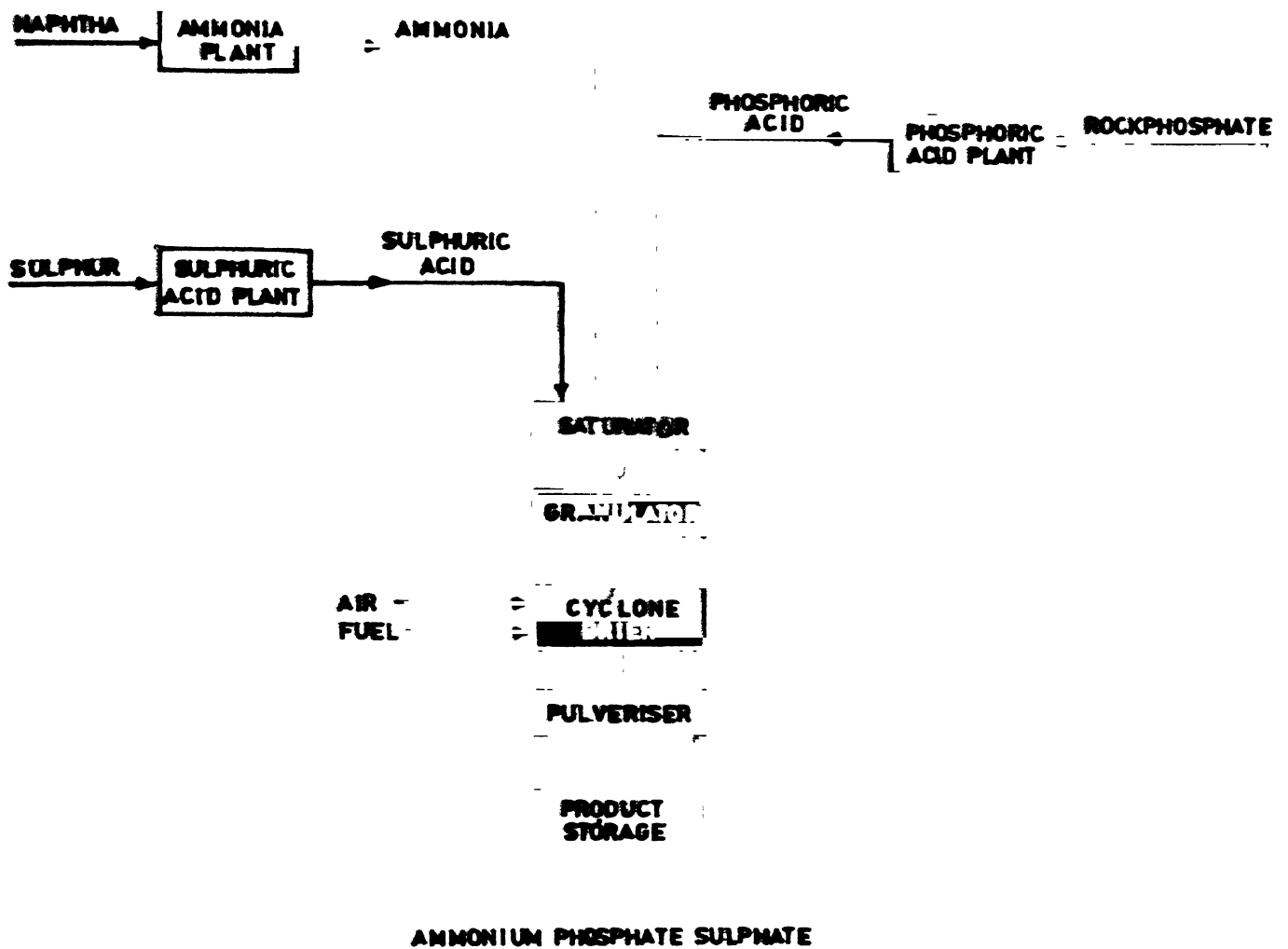


Fig. 5.1 Process Flow Diagram for Ammonium Phosphate Sulphate Production

Table 5.5

Specific Energy Consumption in the Manufacture of Ammonium Phosphate Sulphate (APS)^{1/}

Year	1	2	3	4	5
Energy Consumption (Gcal/tonne) ^{2/}	5.38	4.99	4.77	4.70	4.48
Capacity Utilisation (%)	99	94	89	91	91

1/ For one plant only

2/ 1 Gcal = 10^9 calories
 1 calorie = 4.18 Joules

Source: Computed from study questionnaire response.

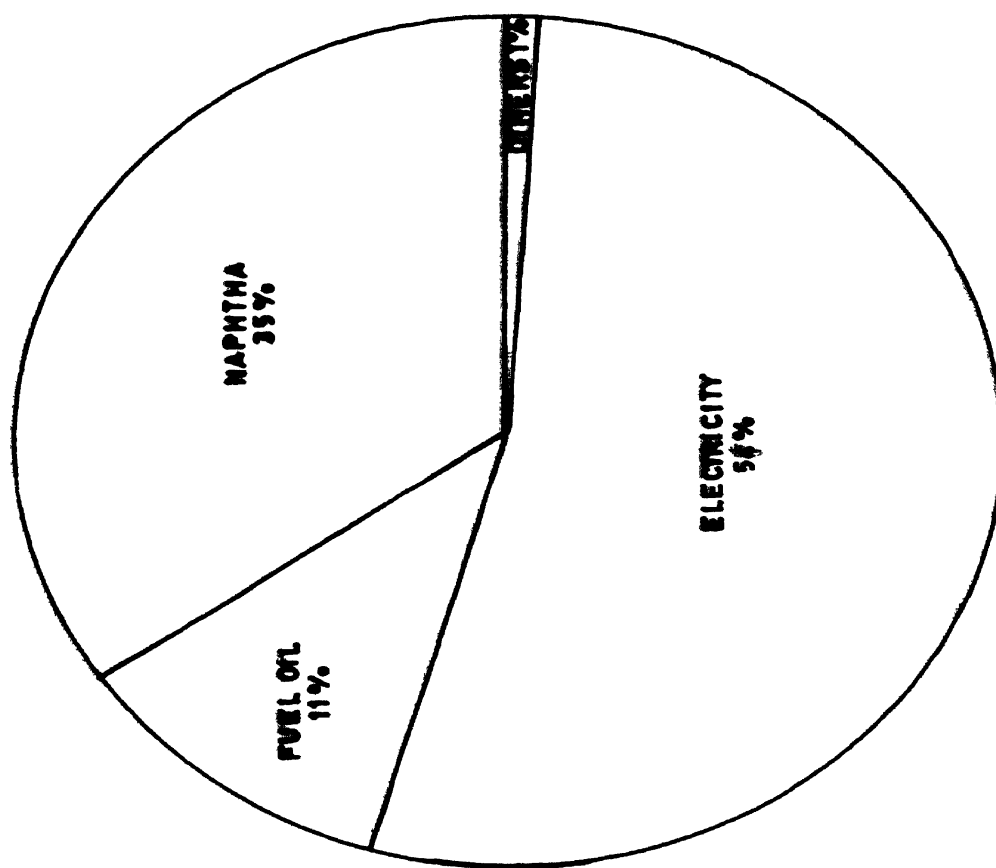


Fig. 5.2 Break up by Energy Forms in Ammonium Phosphate Sulphate (APS) Manufacture

Note: Numbers are for a single plant

ANNEXURE 1

THERMAL CONVERSION VALUES OF DIFFERENT FORMS OF ENERGY AND UTILITIES

Energy Form	Unit	Thermal Conversion Values (Gcal)
Electricity	MWh	4.00 ^{2/}
Coal (non-coking)	Tonne	5.00
Fuel Oil	Tonne	10.00
Naphtha	Tonne	11.00
Light Diesel Oil	Tonne	10.00
Power Alcohol	Tonne	5.00
High Speed Diesel Oil	Tonne	10.00
Liquid Petroleum Gas	Tonne	11.60
Natural/Associated Gas	1000 m ³	9.19
Pumped Water	1000 m ³	1.00 ^{3/}
Steam	Tonne	0.874 ^{4/}

1/ 1 Gcal = 10⁹ calories
1 calorie = 4.18 Joules

2/ The overall thermal efficiency of electricity generation is taken as 20 %

3/ Energy needed to pump 1000 m³ of water over an equivalent distance of 5 km

4/ Steam at 40 atms, 350°C

